BELLCOMM, INC.

SATURN V
PROPELLANT LOADING SYSTEM
STUDIES

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ABSTRACT

These studies conclude that propellant loading can be accomplished to essentially the accuracy of the mass sensor and the calibration of the tank without requiring a separate major digital computer. The work supports a recommendation to use an analog control system with monitoring by the Launch Control Computer.

Mass sensors and tank calibration means which have sufficient accuracies to allow completion of the propellant loading task prior to pressurization would significantly simplify operational procedures, and should be made the objective of an active development program.

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PROPELLANT LOADING SYSTEM STUDIES

1. Introduction

Studies have been made by Bellcomm relative to features of the Propellant Loading System that is to be used in loading the propellants in Saturn V launch vehicle stages at Cape Kennedy. These formed a part of a review of this total system conducted by the Launch Support Engineering Division of the Kennedy Space Center.

These studies centered on specific areas of the propellant loading system, but were kept sufficiently broad so that the influence of the effectiveness of the complete loading system would be understood.

The original broad questions which precipitated a review included:

1. Is a separate major digital computer (GE 236) required to accomplish propellant loading?
2. Will the planned system meet the loading accuracies required?
3. Are there alternate methods of accomplishing the task or portions of the task which might be employed to reduce complexity but still meet operational requirements?

Bellcomm was asked to give consideration to:

1. the effect of mass sensor accuracies on the ground loading system,
2. the effect of mass sensor noise on the ground loading system,
3. the dynamics of the cryogenic replenish and topping systems,
4. the magnitude of the tasks required of a digital control computer system, and
5. conceptual solutions using respectively the digital launch control computer (RCA 110A) and analog servo systems to accomplish the task.

2. Mass Sensors - Tank Calibrations[1]

Four types of sensors which can be used to measure the mass of propellant in a tank are vented capacitance probes, manometer (closed-sides) capacitance probes, differential pressure (Δ-p) sensors, and point level sensors.

Full length vented probes are planned for the S-IVB, full length manometer probes for the S-II, short length (top 5%) probes for the S-IC, Δ-p for the S-I and S-IB, and point level sensors for discrete signals from each of these stages.

Sensors of these types have been shown to be capable of giving accuracies in the range 0.1 - 1.0%. It appears probable that Saturn V sensor system accuracies will fall in the 0.25 - 0.50% loading accuracy requirement range. However, because of the lack of test data, this statement must be regarded as an estimate.

Two cryogenic propellant characteristics which affect mass sensor accuracy significantly are propellant density and propellant boiling. The effects of these are augmented in tanks of non-uniform cross section. This is important in Saturn V tanks as the 100% levels of propellants are in the hemispherical tank domes. The influences of density on the capacitance probes and on the Δ-p probe are expected to justify density determinations so that corrections may be made.

The boiling of the propellants causes turbulence and waves which will result in a.c. noise on the sensor outputs, particularly on that of the vented probe. Also, bubbles in the liquid will tend to raise the level of the liquid surface and result in a bias or shift in the sensor outputs. This effect is also expected to be greater in the vented probe than in the manometer probe or the Δ-p sensor. The effects of boiling will be functions of the boil-off rate which in turn is a function of the weather. These effects are expected to disappear rapidly upon pressurization of the tank.

A point to be emphasized is that the development programs are at stages where the ultimate mass sensor system and tank calibration accuracies for Saturn V have not yet been established.

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[1]See Reference List.

3. Cryogenic Filling System Dynamics

Replenishment of cryogenic propellants lost due to boil-off, and final adjustment (topping) of the mass to the flight value, are two closed loop control processes. The amount of the fuel in the tank must be sensed, compared against a reference, and the difference used to control liquid flow into the tank.

Examination[2] of the control systems to accomplish these tasks included analytical studies and digital computer simulations. The simulations verified the results of the analytical studies.

Parameters important in the study work included the rate at which the sensor was sampled by the DDAS (PCM) system, the amount of filtering or averaging of the signals required to suitably reduce mass reading noise, the rate at which differences from desired mass should be corrected by the control system, the frequency with which new valve flow rates should be calculated, and the effect of using a digital rather than an analog (or continuous control) valve.

The capacitor probe sensor noise used was derived from records including those of the liquid hydrogen loadings of the S-IV stage of SA-5. These were interpreted to give a worst-case value for Saturn V cryogenic sensors.

The following remarks are directed to the replenish control system. It must correct any discrepancies accurately, but it is not required to do so quickly. This leads to the use of a relatively slow control system; the system studied approaches the reference level exponentially with a time constant of five minutes. This provides a natural means for reduction of the effects of noise on mass sensor signal.

Other parameters assigned included a valve calculation and setting interval of 15 seconds, and the use of a digital valve having 32 uniform steps.

The mass errors disclosed by the study of the replenish control system are shown in Table 1 and are small in comparison to the ground equipment error allowance of 0.3%.

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[2] See Reference List.

Some remarks are now directed to the topping control system. The system analyzed is the one being considered for use in completing the loading of the S-II and S-IVB stages after pressurization of the tanks. It causes the propellant mass to increase from a value just below flight load, to flight load, by running at full replenish valve rate. Full replenish flow starts at tank pressurization and continues until the filtered value from the mass sensor matches the reference mass. This signals cut-off of propellant flow and indicates flight load.

Principal parameters in this topping control system are sensor noise, sampling rate, noise filter constants and the time interval between comparisons of measured mass and reference mass. The values assigned, and the results of the analysis are shown in Table 2. The mass errors shown in this table are also small in comparison with the ground equipment error allowances of 0.3%.

The mass adjustment that can be made during final topping has been calculated and is shown in Table 3. The calculations are based on the maximum replenish rate being set at three times the expected boil-off rate.

The small amount of mass adjustment possible imposes a tight requirement on accuracy of mass determination prior to pressurization. In fact, the accuracy required to make this topping system feasible practically eliminates the need for topping.

4. Digital Computer Load

After examining the various functions of the propellant loading system and identifying those that should be assigned to a central digital computer, a study[3] was made of the computer time loads.

The study included the operational requirements arising from the actions necessary to load, replenish and top off the various tanks, plus display, control, generation of discretes, and the test and simulation requirements needed to prepare the system and check its performance.

Individual time estimates of GE 236 and RCA 110A loading were obtained by writing programs for the time critical tasks, and estimating running time for the remaining tasks.

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[3] See Reference List.

The total time estimates are 1.7% for the GE 236 and 12.9% for the RCA 110A.

An 8000 word memory would be needed with either computer.

5. Use of Separate Digital Computer

The GE 236 can be used in the ground portion of the loading system and will accomplish the task well.[4]

6. Use of Launch Control Computer

No significant equipment will have to be added to the propellant loading system to allow the Launch Control Center RCA 110A to replace the GE 236 computer for the task. The propellant loading sensor data, already on DDAS, can be transferred to the computer at a one per second rate. Valve orders in digital form, and system discretes, may be sent over the already planned transmission systems to the Pad Terminal Connection Room and the Launcher-Umbilical Tower.

7. Use of Analog Control Servos

Analog control systems can be used to achieve satisfactory control of replenishing and topping. The analog mass signal can be compared against a reference and the difference used to control the replenish valve. Mass signals may also be transmitted to ratiometers which will generate signals for control of the propellants and gases networks, as well as for mass readout and display.

8. Discussions and Conclusions

Ground Loading System

Using existing arts each of the systems considered can be made to meet the ground loading system requirements, and in particular the ground system accuracy requirements.

The use of a GE 236 computer results in the greatest hardware complexity, the use of the RCA 110A results in the least complexity and the analog system is intermediate between

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[4]Reference 4 discusses ground equipment configurations.

the two. Based on these considerations alone, the RCA 110A solution is most attractive, followed by the analog system and GE 236 in this order. However, some of the RCA 110A advantage over the analog system is offset by a software development effort. Furthermore, the RCA 110A system and the propellant loading system are being designed and developed by different Centers.

In comparing the RCA 110A system with the analog system, the choice lies between a moderate amount of simplification coupled with an involved inter-center interface problem on one hand and somewhat greater hardware complexity on the other. Bellcomm concurs with and supports the recommendations[5] of the Launch Support Engineering Division Study to:

1. select the analog system to accomplish the propellant loading task, and

2. use the RCA 110A system to monitor the status of the propellant loading system.

<u>Mass Sensors - Tank Calibrations</u>

In the course of the study work other conclusions were reached by Bellcomm:

1. Practical means are available to reduce the effects of the a.c. noise from the sensor to a negligible mass error.

2. Ultimate loading system accuracies are not known. In the present state of development, sensor and tank calibration accuracies are limiting and do not meet Saturn V requirements.

3. Mass sensor and tank calibration development objectives should include requirements for requisite accuracy in unpressurized tanks to achieve significant simplifications in equipments and in operations.

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[5] These recommendations have subsequently been approved.

TABLE 1

REPLENISH CONTROL SYSTEM

Conditions:		
	Servo Time Constant	- 5 Minutes
	Valve Reset Interval	- 15 Seconds
	Digital Valve	- 32 Uniform Steps
	Filtering	- Simple Averaging Over 15 Second Interval
	Noise (3 Standard Deviations)	- 0.9% of Mass for S-IVB; Scaled for Other Tanks
	Telemetry Rate	- 4 Per Second and 1 Per Second

System	Mass Errors %: Due* to Noise with Telemetry Rate = 1/sec.	Mass Errors %: Due* to Noise with Telemetry Rate = 4/sec.	Mass Errors %: Digital Valve Error
LOX S-IC	0.025	0.01	0.015
S-II	0.005	0.003	0.003
S-IVB	0.016	0.008	0.010
LH_2 S-II	0.022	0.011	0.013
S-IVB	0.037	0.018	0.022

*Three standard deviations -- less than this 99.7% of time.

TABLE 2

TOPPING CONTROL SYSTEM

Mass Comparison Interval	- 5 Seconds
Filtering	- Simple Averaging Over 15 Seconds
Noise (3 Standard Deviations)	- 0.225% of Mass for S-IVB, Scaled for Other Tanks
Telemetry Rate	- 4 Per Second and 1 Per Second

	Mass Error - % (3 Standard Deviations)	
System	Telemetry Rate = 4/sec.	Telemetry Rate = 1/sec.
LOX S-II	0.006	0.009
S-IVB	0.017	0.028
LH_2 S-II	0.024	0.040
S-IVB	0.040	0.067

TABLE 3

FINAL TOPPING TIMES AND QUANTITIES

Maximum Replenish Rate = 3 Times Boil-Off Rate

System		Pressurization Time	Fill and Drain Valve Closure Time	Topping Time	Maximum Percent Mass Adjustment
LOX	S-II	T-540 Seconds	T-250 Seconds	290 Seconds	0.517%
	S-IVB	T-90 Seconds	T-30 Seconds	60 Seconds	0.121%
LH_2	S-II	T-180 Seconds	T-30 Seconds	150 Seconds	0.595%
	S-IVB	T-90 Seconds	T-30 Seconds	60 Seconds	0.468%

Notes: Times and estimated boil-off values from MSFC P&VE

K-D indicates that it may be necessary to reduce the maximum replenish rate to less than 3 times the boil-off rate; this would reduce the available adjustment.

BELLCOMM, INC. May 22, 1964

Reference List

Additional information on the subjects discussed in this report is given in the memoranda listed below. This material has not been included or appended as it is too detailed for general distribution. Copies of these memoranda are being supplied to Mr. C. T. Wasileski, K-D.

1. Memorandum for File - Studies on Cryogenic Mass Sensors for Saturn V, P. S. Schaenman, May 22, 1964.

2. Memorandum for File - Cryogenic Replenish and Topping Control Systems for Saturn V, J. Kranton, May 22, 1964.

3. Memorandum for File - Saturn V Propellant Loading System Operation and Digital Computer Implementation, J. M. Nervik, May 22, 1964.

4. Memorandum for File - Configurations of Saturn V Propellant Loading Equipments, S. G. Embrey, May 22, 1964.